

EXECUTIVE SUMMARY

This report describes mobile communication link measurements made at Edwards Air Force Base, CA as part of the Flexible Interoperable Transceiver (FIT) program. Edwards Air Force Base (EAFB) is the first of four locations to be measured, the other three being Fort Hood TX, Fort Polk, LA and Camp Lejeune, NC. The goal of the measurement series is to define communication link characteristics at different frequencies over a representative cross section of military installations.

The measurements were made using the ITS multiple channel impulse response system (see Report, Section 3). The primary figures of merit used to characterize wireless communication links are basic transmission loss (L_{BT}) and delay statistics. Three frequencies are considered: 440 MHz, 1360 MHz, and 1920 MHz. 440 MHz is representative of several current ground-to-ground communication links (JRTC-IS, PRIME, PLRS). 1360 MHz is proposed for the next generation FIT system. 1920 MHz has similar characteristics to the 1710-1850 MHz band, which is also under consideration for FIT. By comparing the 1360 MHz and 1920 MHz basic transmission loss and delay statistics to those for 440 MHz, the viability of using higher frequencies for future military communications and the associated system requirements can be assessed.

For this study two transmitter sites were chosen. Site 1 was located near the flight line and hangers. The ground elevation at this site was 701 m and the transmitter antennas were at a height of 706 m. This site was chosen to simulate a low, close in transmitter, in the clutter of the flight-line buildings. Such a site might be used to communicate with aircraft on the flight line and personnel and data terminals near the flight line buildings. Site 2 was placed on the roof of the AF-38 radar site on a prominent hill. Ground elevation at the site is 805 m and the transmitter antennas were at an elevation of 809 m. This site was chosen as representative of an optimum transmitter site for long range communication (see Report, Section 2).

Data were collected simultaneously at three frequencies along multiple drive routes (short range, long range). This allowed a direct comparison of basic transmission loss and delay statistics in several representative environments. The major question answered by the survey are the effects of frequency translation on these radio propagation parameters. To quantify propagation impairments caused by frequency translation, the impulse response data were analyzed and the following metrics tabulated:

1. Linear curve fit parameters n (path loss exponent) and B (multiplier) are tabulated for basic transmission loss (L_{BT}) versus distance for three frequencies. This data is summarized in tables ES1-ES4. The path loss exponent, n , is the critical parameter. For line-of-sight propagation with free space loss (L_{FS}), $n = 2$ (for example, see Cell 2 Route 2, Figure 4.4). In areas with obstructions caused by terrain, vegetation, or buildings n typically varies between 2 and 4 due to multipath interference (see Cell 1 Route 1, Figure 4.1). Full shadowing can cause the path loss to be more or less independent of distance (D) and results in loss exponents less than 2 (see Cell 2 Route 1, Figure 4.3). Column one in Tables ES1 through ES4 shows the n and B parameters

(see Report, Section 4 for more details). By substituting these parameters into the curve fit equation a best fit approximation of path loss versus distance can be calculated for the different frequencies and routes. These curves then are used in conjunction with the free space loss curve to determine additional loss over free space ($\Delta L_{BT/FS}$) for specific transmitters and routes. They also are used to determine signal loss due to frequency translation from 440 MHz to higher frequencies ($\Delta L_{BT/440}$).

2. $\Delta L_{BT/FS}$ is used to designate the difference between the linear fit to the measured basic transmission loss and ideal free space values. These data then indicate the additional loss over the basic free space loss for the measured frequencies. The $\Delta L_{BT/FS}$ data range is approximately 20 to 40 (dB) for Cell 1 (low transmitter) and 10 to 20 (dB) for Cell 2 (high transmitter). The lower differences for Cell 2 indicate the better line of sight coverage for the high transmitter site. Tables ES1 through ES4 and Report Section 4 give these data at multiple distances.
3. The difference between the 1360 and 1920 MHz linear fit estimates and the 440 MHz linear fit estimate is designated $\Delta L_{BT/440}$. These numbers can be used to determine the extra transmit power, system sensitivity, diversity gain, or BER versus signal-to-noise requirements of the proposed higher frequency systems. The $\Delta L_{BT/440}$ data range over approximately 5 to 15 dB for the 1360 MHz data and 10 to 20 dB for the 1920 MHz data (see Tables ES1 through ES4 and Report, Section 4).
4. An alternative to curve fitting the measured data is to bin the L_{BT} data. This is done versus distance and the mean, and standard deviation for each bin are calculated as well as the 90% and 99% probability levels (i.e. 99% of the L_{BT} data are less than this level). 99% L_{BT} levels range from 126 to 163 dB in Cell 1 and from 117 to 157 dB in Cell 2. These data give the upper bounds for the measured transmission loss, L_{BT} , and indicate maximum signal loss on the link required to ensure a certain channel availability probability (see Tables ES5 and ES6 and Report, Section 4). The difference between the mean and the 99% level also can be added to the curve fit to extend the curve fit requirements to the 99% availability level.
5. Delay statistics are necessary for design of a digital system. They are used to determine equalizer requirements for elimination of inter-symbol interference. In general, delay increases with frequency and with the presence of scattering objects (low transmitter). Two figures of merit are the delay spread and the maximum delay. At 90% probability, the maximum delay ranges from 8.7 μ s (low transmitter, long-range route) down to 5.6 μ s (high transmitter, long range route) for 440 MHz and from 19.0 μ s down to 7.7 μ s for 1920 MHz. These data are based on a 20 dB interval of discrimination (impulse peak to noise > 23 dB, only echoes within 20 dB of the peak are included in the statistics). For a 10-dB interval of discrimination and 90% probability, the maximum delays reduce from 5.2 to 0.2 μ s and from 10.5 to 0.5 μ s for 440 and 1920 MHz respectively for low and high transmitters and long routes. The delay spreads are up to 2.2 μ s for 440 MHz and up to 4.1 μ s for 1920 MHz (see Report, Section 5 for more details). In addition, impulse data can be used through simulation to determine the optimum equalizer design.

Table ES1. Curve Fit Parameters, Free Space Loss and 440 MHz Loss Compared to Basic Transmission Loss Data, Cell 1 Route 1 (Low Transmitter, Short-Range Route)

	L_{BT} Linear Fit Parameters		D 0.7 km		
F (MHz)	n	B (km^{-1})	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)
440	3.8	9.0e+2	82.2	24.2	0.0
1360	3.1	9.1e+3	92.0	26.0	11.6
1920	4.1	1.0e+3	95.0	21.9	10.5

Table ES2. Curve Fit Parameters, Free Space Loss and 440 MHz Loss Compared to Basic Transmission Loss Data, Cell 1 Route 2 (Low Transmitter, Long-Range Route)

	L_{BT} Linear Fit Parameters		D					
			3.0 km			8.0 km		
F (MHz)	n	B (km^{-1})	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)
440	1.9	1.6e+6	94.9	31.9	0.0	103.4	31.5	0.0
1360	4.6	2.5e+2	104.7	27.2	5.1	113.2	38.3	16.6
1920	3.9	1.1e+3	104.7	29.8	10.7	116.2	37.8	19.2

Table ES3. Curve Fit Parameters, Free Space Loss and 440 MHz Loss Compared to Basic Transmission Loss Data, Cell 2 Route 1 (High Transmitter, Short-Range Route)

	L_{BT} Linear Fit Parameters		D					
			4.5 km			6.5 km		
F (MHz)	n	B (km^{-1})	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)
440	0.7*	3.3e+15	98.4	14.9	0.0	101.6	12.8	0.0
1360	0.9*	4.8e+13	108.2	20.8	15.7	111.4	19.0	16.1
1920	1.0*	4.5e+12	111.2	21.8	19.8	114.4	20.2	20.2

* values lower than free space are due to shadowing

Table ES4. Basic Transmission Loss, L_{BT} , Data for Cell 2 Route 2 (High Transmitter, Long-Range Route)

	L_{BT} Linear Fit Parameters		D					
			2.0 km			20.0 km		
F (MHz)	n	B (km ⁻¹)	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)
440	2.1	4.5e+4	91.3	12.8	0.0	111.3	13.8	0.0
1360	1.9	1.1e+6	101.1	19.1	16.2	121.1	18.1	14.2
1920	1.7	2.8e+6	104.1	10.7	10.7	124.1	7.7	6.7

Table ES5. Cell 1, Free Space Loss, L_{FS} , and Measured Mean, 90%, and 99% L_{BT} Levels

D (km)	L_{FS}	L_{BT} (dB): 440 MHz			L_{FS}	L_{BT} (dB): 1360 MHz			L_{FS}	L_{BT} (dB): 1920 MHz		
		Mean	90%	99%		Mean	90%	99%		Mean	90%	99%
0.6	81.5	102.5	112.9	118.0	91.3	118.2	130.3	134.0	94.3	112.2	124.1	126.7
1.0	85.7	107.6	113.4	118.7	95.5	124.5	133.0	137.9	98.5	118.8	132.2	135.8
2.1	91.6	121.3	129.3	131.8	101.4	132.9	140.9	149.6	104.4	131.6	138.3	142.6
3.1	95.0	131.7	141.1	144.7	104.8	144.9	156.5	160.7	107.8	143.5	152.8	155.1
4.1	97.5	134.0	140.3	142.8	107.3	150.7	159.0	162.5	110.3	149.4	156.6	159.4
5.1	99.4	134.5	144.3	146.9	109.2	153.9	163.8	165.2	112.2	151.6	161.0	162.9
6.1	101.0	134.7	144.8	146.6	110.8	149.8	163.3	165.0	113.8	143.5	160.7	162.4
7.1	102.3	127.4	136.2	137.7	112.1	157.5	164.2	165.3	115.1	155.0	162.8	163.5
8.1	103.5	140.2	141.9	142.6	113.3	152.4	154.5	156.2	116.3	154.0	156.3	158.3

Table ES6. Cell 2, Free Space Loss, L_{FS} , and Measured Mean, 90%, and 99% L_{BT} Levels

D (km)	L_{FS}	L_{BT} (dB): 440 MHz			L_{FS}	L_{BT} (dB): 1360 MHz			L_{FS}	L_{BT} (dB): 1920 MHz		
		Mean	90%	99%		Mean	90%	99%		Mean	90%	99%
1.0	85.7	100.3	102.8	104.2	95.5	112.4	115.0	116.3	98.5	117.3	126.2	129.6
1.7	89.9	95.4	100.7	104.1	99.7	108.2	110.6	111.6	102.7	111.8	116.1	117.6
3.0	94.8	103.5	107.8	115.8	104.6	117.3	121.6	128.7	107.6	115.6	122.1	127.1
4.9	99.2	121.3	130.4	137.1	109.0	132.6	148.8	156.7	112.0	132.0	147.5	153.9
6.9	102.0	112.9	118.6	121.3	111.8	125.0	133.7	138.2	114.8	120.7	138.6	142.1
8.8	104.2	122.3	126.4	129.7	114.0	131.9	148.8	150.9	117.0	126.5	152.1	154.7
10.1	105.4	126.2	133.7	137.2	115.2	136.0	147.8	150.1	118.2	133.5	146.1	148.9
12.0	106.9	118.8	122.2	124.0	116.7	132.2	134.7	136.5	119.7	124.1	126.9	129.1
14.0	108.2	122.4	125.7	127.0	118.0	129.5	135.0	136.2	121.0	122.3	124.3	125.1
15.9	109.3	124.2	126.9	130.9	119.1	128.5	139.0	139.5	122.1	126.5	136.8	137.5
17.8	110.3	123.0	124.8	126.6	120.1	134.0	143.7	146.5	123.1	129.0	140.2	145.3
19.8	111.2	122.0	123.8	128.2	121.0	131.2	133.9	134.4	124.0	126.2	130.5	133.5
23.0	112.5	123.3	124.5	125.2	122.4	137.7	139.8	140.1	125.3	133.7	135.0	135.4
25.6	113.5	126.8	133.9	138.4	123.3	145.4	153.2	161.0	126.3	140.9	151.0	156.9